

SODA-RICH ANTHOPHYLLITE ASBESTOS FROM
TRINITY COUNTY, CALIFORNIA

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Samples of asbestos fiber and asbestos in serpentine from Coffee Creek, one mile north of Carville, Trinity County, California, were brought to our laboratory by Mr. J. M. Cowan of South Pasadena, California. One of us (Woodford) later visited the locality, a series of small, closely-spaced prospect pits on the rather steep slope at the south side of the mouth of Coffee Creek, a tributary of Trinity River. The country rock is serpentine, commonly showing bastite pseudomorphs. The serpentine contains two types of veins: (1) the usual minute, branching veinlets of chrysotile, less than a millimeter wide, and (2) much thicker amphibole asbestos veins. Practically none of the coarse asbestos is now exposed in the walls of the prospect pits, but some can be found in the rock on the dumps.

The thick veins look like dark-colored chrysotile, but are exclusively amphibole. They are short, branching, of variable width, and lie in the crushed, slickensided rock in very roughly parallel positions. The thickness of the different veins ranges from a few millimeters to five centimeters, and a single vein may pinch out very rapidly. Exceptionally a vein with maximum width of one centimeter may be only five centimeters long. The fibers are usually perpendicular to the walls, although in some veins oblique, and commonly almost as fine and flexible as commercial chrysotile. Some veins, but not all, have slickensided margins, along which the fibers have been dragged. The color of the separated fibers is white, but on fresh breaks the veins usually have the color called by Ridgway 33''''m, Dull Greenish Black.¹ There is a range from Black to 33''''k, Dark American Green, but no correlation could be made between depth of color and optical properties.

A microscopic study was carried out on thin sections and oil mounts. Indices were determined in oils, using white light, and the oils checked at once with a Spencer Abbe refractometer. The long-fibered asbestos was found to be chiefly pale, low-index

* Chemical analysis by J. D. Laudermilk; optical study by A. O. Woodford.

¹ Robert Ridgway, *Color Standards and Color Nomenclature*, 43 pp., 53 pls., *Washington, 1912.*

anthophyllite ($\gamma = 1.623-1.625$; in standard thin-section X and Y colorless, Z Ridgway's 35''f, Pale Olivine), with lesser amounts of higher-index, greenish anthophyllite (γ about 1.630-1.635), and tremolite or actinolite ($\gamma = 1.622 \pm .002$, extinctions up to 12° and perhaps higher). In several cases a single vein yielded two types of amphibole.

The "No. 1 fiber," a composite sample furnished by Mr. Cowan, was chosen for chemical analysis. It was found by microscopic study to be chiefly anthophyllite with the following indices: $\alpha = 1.606 \pm .002$, $\beta = 1.613 \pm .002$, $\gamma = 1.623 \pm .001$. Parallel to the elongation of the fibers (Z) the color is pale yellow-green; the other directions are colorless except in thick bundles. There is also present in the sample some anthophyllite with slightly higher indices ($\gamma = 1.625 \pm .002$), and a deeper color. One exceptional fiber was found with a still higher value for γ , approximately 1.630. A few fibers show slightly inclined extinction (5° or less) and may be tremolite ($\gamma = 1.622 \pm .002$). Non-amphibolic impurities were estimated to make up less than 2%; they included iron oxide spots and stains, as well as minute grains of quartz, and perhaps serpentine and other minerals. The asbestos has easy fusibility, about 3, and colors the flame intensely yellow. The material is practically insoluble in acid. For the analysis half-gram samples were used. The average of closely agreeing duplicates, together with the molecular ratios, follows:

	WEIGHT PER CENT	MOLECULAR RATIOS
SiO ₂	57.70	.9607
TiO ₂	absent	
Al ₂ O ₃	2.00	.0196
Fe ₂ O ₃	trace	
FeO	5.32	.0741
MgO	21.12	.5238
CaO	5.10	.0910
Na ₂ O	7.40	.1194
K ₂ O	absent	
MnO	trace	
F	absent	
H ₂ O above 110°	1.80	.0999
H ₂ O below 110°	0.30	—
TOTAL	100.74%	

The analysis may also be expressed in molecular percentages of metasilicates, as follows:

NaAl(SiO ₃) ₂	6.25%
Na ₂ SiO ₃	10.61
MgSiO ₃	55.66
FeSiO ₃	7.87
CaSiO ₃	9.67
H ₂ SiO ₃	9.94 (Excess of .0064 H ₂ O+ in mol. ra- tios not used.)
TOTAL	100.00%

Although there is an excess of bases, it is so small as to favor the exclusively metasilicate interpretation given. If Al₂O₃ were considered present in solid solution only, the deficiency of bases would be eight times the excess here shown. Of the molecules mentioned by Winchell² only MnSiO₃ is missing. Soda is so high as to require NaAl(SiO₃)₂ and Na₂SiO₃, constituents not in Winchell's list.

Very few other anthophyllite analyses show appreciable soda, and none known to us is as high in soda as the Coffee Creek material. Doelter³ gives one high-alkali "antholith," with K₂O plus Na₂O = 5.93% (also Fe₂O₃ = 8.03%), analyzed by van der Bellen, who gives neither locality nor optical data in the original paper.⁴ Van der Bellen mentions the light blue color, fineness and softness of this asbestos. It melted at Cone 1 (1150°C.) and lost 5% by cooking in HCl. Van der Bellen's data and ours, taken together, suggest that soda-rich anthophyllite asbestos is relatively soft and flexible.

According to Winchell's chart, showing "Variations of composition and optic properties in the anthophyllite series,"⁵ the indices of our analyzed material correspond to about 11 percent by weight of FeSiO₃ and 89 weight percent of MgSiO₃. Our analysis corresponds to slightly less than 10 weight per cent of FeSiO₃, and 90+ percent of the other constituents. If only FeSiO₃ (plus MnSiO₃) and MgSiO₃ are considered, as was done in preparing the Winchell chart,^{5a} then our analysis would be represented by 15.7 weight percent of FeSiO₃, and 84.3 weight percent of MgSiO₃. It seems that small amounts of soda, and probably lime also, have approximately the same effect upon the indices as does magnesia and that in the case of soda-rich anthophyllite the

² N. H. and A. N. Winchell, *Elements of Optical Mineralogy*, 2nd Ed., Part II, p. 202, 1927.

³ C. Doelter, *Handbuch der Mineralchemie* II, 1, p. 606, 1914.

⁴ E. van der Bellen, *Beitraege zur Kenntniss des Asbestes*, *Chemiker-Zeitung*, 1900, pp. 392-393.

⁵ Winchell, *Loc. cit.*, p. 204.

^{5a} Private communication from Professor A. N. Winchell.

Winchell diagram indicates more $MgSiO_3$ than is present.

Slavík and Veselý⁶ have objected to the extension beyond 30% (Fe, Mn) SiO_3 of the practically straight-line Bowen chart for anthophyllite,⁷ and their data may require a slight alteration in the Winchell curves. Moreover, it appears that even in the relatively simple anthophyllite series, refractive index curves must be supplemented by other data in order to obtain an adequate idea of chemical composition.

Unlike the Trinity material, most anthophyllite and other amphibole asbestos seems to occur in long-fibered bundles or irregular aggregates. When in veins it is fibrous parallel to the walls.⁸ However, Merrill quotes Heddle as reporting "amianthus"⁹ (tremolite) from cross-fiber veins in Scotland. More recently Peacock¹⁰ and Slavík¹¹ have reported high-iron and high manganese anthophyllite asbestos in veins with cross-fiber structure. Whatever may be the causes of some such structures, for the Trinity occurrence recourse can hardly be made to Mügge's gel-shrinkage hypothesis,¹² which was developed from a study of the Reichenstein, Silesia, serpentine. This explanation seems to be eliminated here by the preservation of the bastite structures. Peacock's¹³ suggestion of control by loss of the solvent through the walls of the seams is very attractive, especially in view of his evidence that crocidolization is accompanied by dehydration. The formation of the short, wide fissures was perhaps due to stresses set up during development of the serpentine from the pre-existing rock.

⁶ Fr. Slavík and V. Veselý, Manganiferous anthophyllite asbestos from Chvalčice: *Rozpravy České Akad.*, **36**, Nr. 46, pp. 1-7, 1 Text fig. French summary in *Bull. intern. de l'Ac. de Sci. de Boh.*, 1927, Praha, 1927. Abstracts in *Neues Jahrbuch, Referale*, **1**, 1929, pp. 120-121, and in *Mineralogical Abstracts* **3**, 508, 1928. Original paper not seen.

⁷ N. L. Bowen, Optical properties of anthophyllite: *Jour. Wash. Acad. Sci.*, **10**, 411-414, 1920.

⁸ G. P. Merrill, Notes on Asbestos and Asbestiform Minerals: *Proc. U. S. Nat. Mus.*, **18**, 281-292, 1895, especially p. 289.

⁹ *Loc. cit.*, p. 286.

¹⁰ M. A. Peacock, The Nature and Origin of the Amphibole-Asbestos of South Africa: *Am. Mineralogist*, **13**, 241-286, 1928, especially pp. 259-265.

¹¹ Fr. Slavík, Note sur l'anthophyllite asbeste manganésifère des mines de Jacobeni-Arsita: *Ann. sci. univ. Jassy*, **15**, 133-135, 1928. Abstract in *Mineralogical Abstracts*, **3**, 548, 1928.

¹² O. Mügge, Ueber die Entstehung faseriger Minerale und ihrer Aggregationsformen: *Neues Jahrbuch für Mineralogie, Abt. A., Beilage-Band* **58**, 303-348, 1928, especially pp. 338-345.

¹³ *Loc. cit.*, p. 280.